UNCLASSIFIED

AD NUMBER
AD482376
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; MAY 1966. Other requests shall be referred to Arnold Engineering Development Center, Arnold AFS, TN. This document contains export-controlled technical data.**
AUTHORITY
AEDC ltr, 23 Jan 1975

THIS PAGE IS UNCLASSIFIED

AEDC-TR-66-61

HYPERVELOCITY IMPACT CRATER MEASUREMENT METHODS AND ACCURACIES

P. L. Clemens and J. J. Payne

ARO, Inc.

May 1966

~~This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center.~~

This document has been approved for public release its distribution is unlimited. Per AF Letter 23 January 75 Alfred William D. Cole

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

HYPERVELOCITY IMPACT CRATER MEASUREMENT METHODS AND ACCURACIES

P. L. Clemens and J. J. Payne
ARO, Inc.

FOREWORD

The results of research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The research was conducted from May 1, 1965 to February 3, 1966 under ARO Project No. VS3502, and the manuscript was submitted for publication on March 1, 1966.

The authors wish to express their thanks to Mrs. L. H. Welch and Messrs. R. P. Young and A. G. Graziano for their work in making the measurements which support the accuracy assessments reported here. Thanks are also due to Mr. Graziano for his assistance in perfecting the method of wall coating to enable control over meniscus errors in the measurement of volumes.

This technical report has been reviewed and is approved.

John W. Hitchcock
Major, USAF
AF Representative, VKF
DCS/Test

Jean A. Jack
Colonel, USAF
DCS/Test

ABSTRACT

Use has been made of cavities, machined in a typical hypervelocity impact target material, to evaluate methods used to measure volumes, depths, and diameters of impact craters. Depth and diameter measurement techniques in use have been found to produce errors, typically, of 0.1 and 0.5 percent, respectively. The liquid metering method of volume measurement has been found to produce large errors (7 to 44 percent) when applied in conjunction with the saturation wetting which is common. Wall coating and selective adjustment of wetting properties of the filling agent have been shown to provide effective means for minimizing meniscus errors; errors smaller than two percent result in cases where diameter is 0.5 in. or more and total volume exceeds 0.06 cc. The latter technique is inapplicable to accurate measurement of the volumes of small craters (diameters of 0.3 in. or less) wherein capillarity predominates; machining away of crater lips and metering level full produces more satisfactory results.

CONTENTS

ILLUSTRATIONS

TABLES

TABLES (Concluded)

SECTION I
INTRODUCTION

The hypervelocity impact ranges of the von Kármán Facility (VKF) are used for determining the effects of the collisions of high speed, gun-launched projectiles with specially prepared targets. The experimental results are applicable to the estimation of damage to space vehicles by meteoric particles and to evaluation of weapons systems. For thick targets* of any given material, the analytical correlations of impact phenomena are based on relationships among such parameters as: characteristic crater dimensions; projectile velocity; projectile energy, projectile momentum, and material/physical properties and configuration of the projectile. The characteristic crater dimensions which are customarily considered pertinent are diameter, depth, and volume. Exact definitions of these parameters appear later in this report.

Many methods of determining the dimensions of craters produced in experimental work have been investigated in order to develop standardized procedures for use in the VKF. Accuracy and adaptability to a simple production routine were considered most important in selecting the methods to be used. The purpose of this report is to describe the methods which have been adopted and the accuracies inherent within them.

SECTION II
EQUIPMENT AND RESOLUTION LIMITS

A photograph of the major items of equipment used in measuring the crater dimensions is shown as Fig. 1. The equipment consists of a micrometer syringe, a cathetometer, an optical comparator table, a burette, and a modified depth micrometer with adaptor.

The micrometer syringe is used to meter liquids into craters during the making of diameter and volume measurements by techniques described later in this report. The syringe is customarily equipped with a No. 26 hypodermic needle, and it is used only in work with

---

*For the purposes of this report, "thick" targets are to be regarded as those which are not perforated by the projectiles which impact against them.

craters having volumes of approximately 1.5 cc or less. The syringe has a total capacity of 2 cc, and the micrometer barrel is scribed in least subdivisions of 0.002 cc, which equal the limit of volumetric resolution for any single filling operation. (This assumes a least-count ambiguity of 0.001 cc at both starting and stopping of the filling operation; increments of 0.001 cc can be interpolated from the barrel scribings.)

Larger crater volume measurements are made using the burette. The burette has a 150-cc reservoir and a 5-cc stem capacity. The latter is scribed in 0.01-cc subdivisions. Least increments of 0.005 cc can be interpolated, and these establish a 0.01-cc limit of resolution for crater volume measurements made with the burette.

The cathetometer serves simply as an indexing device, and it is used with the optical comparator table, as described later, to obtain measurements of crater diameter. The comparator table traversing mechanism is equipped with a vernier whose least subdivisions enable reading 0.0001-cm increments. Thus, the limit of resolution for any given measurement of diameter becomes 0.0002 cm.

The depth micrometer, modified as later described, and its adaptor are used in the measurement of crater depths. The technique used, which is also described later, involves taking the difference between two micrometer readings to produce each individual measurement of depth. Since the micrometer vernier scale enables interpolation of 0.0001-in. increments, the limit of resolution for depth measurements becomes 0.0002 in.

SECTION III
MEASUREMENT TECHNIQUE

3.1 CRATER VOLUME

Crater volume is defined as the volume of the void enclosed beneath the original target surface and is determined by metering a liquid into the crater. This is done with the target leveled on the comparator table. To determine when sufficient liquid has been added, the metal indicator shown in Fig. 2 is used. The indicator is positioned as shown, and the solution is metered into the crater by the syringe or the burette, whichever is appropriate to the volume being measured. The center leg of the indicator is observed through the cathetometer, and the filling operation is halted at the instant of contact between the

center leg of the indicator and the liquid. Volume is taken as the difference between syringe (or burette) readings before and after filling. Several volume measurements are customarily made for each crater, and the reported volume is the average of these. To better enable observation of the liquid surface, a dye is used. Distilled water is the usual fluid, and 0.1 gm of methylene blue per gallon of water produces a satisfactory coloring.

To minimize error in the volume measurement attributable to meniscus formation, control of the wetting properties of the filling agent must be exercised. Special treatment of the crater wall is also sometimes necessary. These precautions are discussed in detail later in this report.

3.2 CRATER DIAMETER

Crater diameter is defined as the average of wall-to-wall measurements made in the plane of the original target surface. These measurements are made using the cathetometer and the optical comparator table. The crater is filled with a liquid solution whose level is made to occupy the plane of the original target surface, by the technique described above. The cathetometer is moved until the cross-hair is at right angles to the direction through which the comparator table is to be traversed and tangent to the crater wall at the solution level. The table of the optical comparator is then traversed until the cathetometer cross-hair falls tangent to the opposite wall of the crater at solution level. The distance through which the optical comparator table has traveled is noted. The target is then rotated through 45 deg, and the measurement is made again. The average of four such readings is the reported crater diameter; this insures that some account will be taken of irregularities in crater shape.

In the cases of craters of extremely irregular shape, as are often formed in very brittle target materials, an alternative technique is used. The crater lips are milled to the level of the original target surface, and a sheet of thin tracing paper is placed over the target face. A planimeter tracing of the crater periphery is made at the target face to produce a measure of area. The average of several such area measurements (usually three) is taken, and the reported effective crater diameter is the diameter of a circle having equal area.

3.3 CRATER DEPTH

Crater depth is defined as that dimension, taken normal to the original target face, which separates the deepest portion of the crater

from the plane of the original target face. Crater depth is determined using a depth micrometer with an adaptor (Fig. 3). The micrometer has been modified by the machining of its spindle to a conical point. The depth measurements are made by first adjusting the micrometer spindle to contact the plane of the original target surface. This provides the zero reference reading. The spindle is then adjusted to contact the apparent deepest portion of the crater, and the difference between the two measurements is taken as the crater depth. The average of several readings (usually four) is the reported crater depth. It is recognized that there can be only one maximum crater depth; the purpose of averaging is to discount the effect of small irregularities in the crater floor.

SECTION IV
ACCURACY OF MEASUREMENTS

4.1 PREPARATION OF "STANDARD" CRATERS

To assess the accuracies with which crater measurements can be made by the techniques described above, three right-circular cylindrical cavities were machined in blocks of 1100-F aluminum, a typical target material. The diameters and depths of these machined cavities were chosen as being typical of those commonly encountered in impact test work and were measured by standard precision machine shop methods to accuracies of ±0.0001 in. These measurements appear in Table I, and they serve as standards of comparison in the following evaluations of the accuracies of the crater measurement techniques.

4.2 VOLUME

Volume measurements are, as a rule, the most difficult to make accurately. This is attributable to the error introduced by the formation of a meniscus, having finite volume, at the liquid surface-crater wall intersection.* Of course, control over the angle of contact at this intersection is desirable, since such control could be used to minimize or preclude this source of error. However, the contact angle is difficult to control. It varies with temperature and composition

*Assuming a hemispherical crater and discounting capillarity, it can be shown that error in volume measurement attributable to meniscus formation varies inversely as the square of crater diameter.

of the liquid solution used and with changes in the materials and in the cleanliness of the materials with which the solution is brought in contact. (Reference 1 discusses these and related effects.) Owing to the difficulty with which contact angle is controlled, most such work in the VKF (Ref. 2) and elsewhere (Refs. 3 and 4) has relied upon minimizing the contact angle. Reference 2 describes such a technique, recommends the use of water diluted to a one-percent solution of Alconox®, a commercial wetting agent, and shows photographic evidence of the saturation wetting which results.

In order to evaluate the accuracy of the volume measurement results which may be obtained with saturation wetting, the machined cavities, described above, were used as standard craters. For this evaluation, a modified liquid level indicator was made in a design which enabled assessment of meniscus errors. The center leg of the indicator extended beyond the others by 0.1 in. (Fig. 4). This depressed the level of the liquid surface to be observed so that it fell within the cavity. In this way, the presence of a crater lip was simulated, and a wall contact favorable to meniscus formation was provided. The walls of the machined cavities were cleaned with acetone, rinsed with distilled water, and the cavity volumes were measured using the technique already described and the one-percent Alconox-distilled water solution recommended in Ref. 2. The measured volumes were compared with the effective volumes of the cavities, as calculated using measured depths, less the amount of the indicator center leg extension, and measured diameters. Results appear in Table II. Errors of 7.16 to 44 percent are evident. All measurements produced negative errors, as would be expected for wet-wall menisci (contact angles* less than 90 deg).

It is easily demonstrated that the cleaned metallic walls of craters in target materials usually encountered in impact work are wetted even by distilled water to which no wetting agent has been added. Therefore, no adjustment of wetting agent concentration in water can be expected to produce other than finite, negative, volume measurement errors. To establish control over the angle of contact and minimize meniscus errors, it would seem prudent to commence with a solution which would produce the dry-wall case, and increase the concentration of a wetting

---

*Contact angle is defined as that angle, measured within the liquid, which is made with an element of the container wall by an intersecting element contained in the surface of the liquid, at the point of liquid-wall contact. Thus, wet-wall cases are characterized by contact angles less than 90 deg and dry-wall cases by angles greater than 90 deg.

agent until an optimum solution was reached. However, there are few, if any, nonvolatile,* noncorrosive materials which are liquids at room temperature, which do produce contact angles greater than 90 deg in metal walled vessels, and for which wetting properties can be controlled by adjustment of solution. (A near exception is that of pure water in a silver vessel, for which a contact angle close to 90 deg results.) Furthermore, a variety of target materials and a variety of projectile materials (which contaminate crater walls) are common in this work, and no single, nonvolatile, liquid filling agent is likely to exist which will be universally well suited to optimizing accuracy of volume measurements for a variety of primary materials contaminated by a variety of secondary materials. This suggests that a separate evaluation and adjustment of the filling agent would be necessary with each change in target or projectile material in order to produce an optimum for the case at hand.

Figure 5 shows the results of an expedient which avoids these difficulties in most cases where crater size is such that capillarity is negligible. The machined standard cavities were cleaned with acetone and flushed with distilled water. The cavity walls were then sprayed with an aerosol, containing tetrafluoroethylene polymer solids, to produce a thin film coating. Thus treated, the cavity walls are not wetted by distilled water. Volume measurements were made using the modified liquid level indicator, as before, and commencing with dyed distilled water and then progressing through increasing concentrations of the Alconox wetting agent. Each data point plotted in Fig. 5 represents the average of volumes measured during four fillings. It is seen that this wall coating technique provides a means for control over contact angle, hence meniscus error, and that the composition of the filling solution can now be conveniently optimized. Optimum concentration of wetting agent for cavities Nos. 2 and 3 appears, from Fig. 5 to be about 0.05 percent by weight. A solution in this concentration was used to measure the volumes of these cavities. The results appear in Table III, where it is seen that errors no larger than one percent resulted. Data scatter did not exceed two percent. (For the purposes of this report, data scatter is defined as shown in the footnotes of Table III.) This wall treatment technique has now become standard in the VKF for use in the measurement, with improved accuracy, of the volumes of craters of these and larger sizes.

---

*Volatile filling agents are to be avoided because of the errors which result from evaporation during the volume measurement process.

As might have been expected, effects of capillarity rendered the case of the smallest cavity (No. 1) profoundly bi-stable (Fig. 5). Large, more-or-less constant, positive errors appeared for measurements made by careful filling using the micrometer syringe. Mechanical agitation during filling enhanced wetting and yielded large negative errors for the same concentrations of wetting agent. Note, however, that none of the wet-wall cases shown in Fig. 5 produce error values approaching the 44-percent figure which resulted for the same cavity through the use of the previous technique of saturation wetting (Table II). Some investigators (Ref. 5) have found that impact craters of such small size are dealt with effectively by removing the crater lips to the level of the original target surface and then filling level full with the liquid used. This technique excludes both meniscus and capillary errors but introduces the inconvenience of a machining operation and sometimes the risk of error in volume measurement owing to chipping at the crater edges, if the target material is brittle. To evaluate the accuracy of this technique, machined cavity No. 1 was cleaned as before and filled level full, as determined using the unmodified liquid level indicator shown in Fig. 2. The micrometer syringe was used in the filling operation, which was carried out with the 0.05-percent Alconox solution. There was no scatter in four consecutive measurements of the cavity volume. Volume measurement error was 0.17 percent. The numerical results are summarized in Table IV. Machining away of crater lips and volume measurement by this technique is now standard in VKF work with impact craters in this and smaller sizes, where capillarity effects predominate.

Since sloping crater walls are frequently found in impact work, adaptation of the improved method of volume measurement to use with other than vertical walls is of practical interest. Six additional cavities, having sloping walls of various angles, were machined in aluminum for use as standards for a further evaluation of the improved technique. References 6 and 7 describe methods for the measurement of contact angle, and these methods were used to produce the data shown plotted in Fig. 6. Wall treatment and filling agent combinations were selected from Fig. 6 to accommodate the sloping wall angles of the machined cavities, and volume measurements were made as before. Results are presented in Table V, where it is evident that control of contact angle to reduce meniscus by the technique described here enables volume measurements with errors not greater than ±2 percent.

If effectively applied, the wall coating which makes up an essential part of the improved method of volume measurement makes the accuracy of the measurement independent of the kind of target material used. Furthermore, displacement of the liquid filling agent by the wall

coating is easily discounted as a significant source of error. Only the narrow band of crater wall which will serve as a shoreline for the filling agent need be coated; the remainder is easily masked during exposure to the aerosol. This masking precaution was not taken in the work reported here, and cavity interiors were coated throughout. As a result, any contribution to total errors which might be made by this displacement effect appears, multiplied several times over, in the error assessments here.

The evaporation rate of the Alconox-water solutions is less than one percent per hour, as determined using a 0.67-in.-diam hemispherical crater under conditions of room temperature, ambient pressure, and relative humidity closely approximating those customary during the making of crater measurements in the VKF. Since measurements are customarily made within 5-minute durations, the volume measurement error attributable to evaporation is considered negligible.

4.3 DIAMETER

The diameters of the three machined cylindrical cavities were measured, by the cathetometer technique described in Section 3.2, for comparison with the "as-machined" measurements of these same dimensions. The results appear in Table VI. Scatter among the repeated diameter measurements for any given cavity did not exceed two percent. The average scatter in diameter measurements for the three cases was 0.86 percent. The error in diameter measurement, averaged for all cases, was 0.46 percent, and in none of the individual cases did the error exceed 1.04 percent.

It must be noted that the presence of a meniscus will have an influence upon the measurement of crater diameter by this technique. Therefore, minimizing the meniscus is important to the accuracy of diameter measurement, as well as to the accuracy of volume measurement.

The accuracy of measuring the effective diameters of irregularly shaped craters by the planimeter technique described in Section 3.2 was evaluated by using the planimeter to trace the outline of a figure of irregular shape whose area had been determined previously by separate means. Scatter among repeated measurements of area did not exceed 3 percent, and error in area measurement, averaged for the customary three readings, was 1.8 percent. Since area varies as the square of diameter, scatter in effective diameter measurements of 1.5 percent and error of 0.9 percent are implied for this technique.

4.4 DEPTH

As Table VI indicates, depth measurements made by the technique outlined in Section 3.3 were repeatable within one-percent scatter limits. None of the depth measurement errors exceeded 0.27 percent, and the overall average error, for all cases, was -0.05 percent. In the measurement of cavity depth by the technique used here, little human judgment or skill enters. (Note that this is not the case in the measurement of volume or diameter, where skill in liquid metering and judgment of liquid level are involved.) Therefore, the existence of finite errors in the case of depth measurement evaluation implies disagreement in calibration between the depth gases used: (1) in the initial "as-machined" measurement of cavity depth and (2) in the later measurement of depth by use of the micrometer with its adaptor (Fig. 3). In no case did the absolute disagreement between these two measurements of depth exceed 0.0004 in. That values of scatter are small among the depth measurements is attributed not only to the absence of skill and judgment factors, but to the fact that the machined cavities have smooth floor surfaces. Craters produced by hypervelocity impacts have floor surfaces the roughness of which varies with the selection of materials and test conditions.

SECTION V
DISCUSSION AND CONCLUSIONS

Cavities machined into typical hypervelocity impact target materials, and having critical dimensions similar to those of impact craters, are useful in evaluations of measurement techniques applied in determining crater volumes, diameters, and depths. When so evaluated, impact crater diameter and depth measurement methods in use in the VKF have produced maximum errors of 1.04 and 0.3 percent, respectively. The previously used saturation wetting technique of crater volume measurement has been shown to produce appreciably larger errors than does a technique which makes use of wall coating and adjustment of the wetting properties of the filling agent to minimize meniscus through contact angle control. The latter technique appears to be applicable to any metallic materials and produces volume errors of less than two percent in work with cavities machined in aluminum. The wall coating technique is of no value in cases involving small cavities in which effects of capillarity predominate. In such cases, volume measurement errors may be minimized by the more tedious machining away of crater lips and metering to level fill.

While evaluations of these kinds are of convenience in establishing confidence in measurement techniques, or in guiding the choice of one technique from among several under consideration, their worth is limited by an obvious failure in similitude:

> Walls and floors of the machined cavities are smooth, and their geometry is regular; whereas impact crater walls and floors have varying degrees of roughness, depending upon the materials selected, and their geometry may be quite irregular. These differences must always be expected to produce more optimistic values of data scatter among diameter and depth measurements for machined cavities than will be found in actual impact crater measurement work. Data scatter and error values which become evident for the machined cavities will approach limits which are characteristic of the technique of measurement and of the particular items of equipment which are used. The influence of differences in smoothness and geometry upon volume measurement is more problematical. The aerosol surface treatment of rough crater walls might be expected to seal surface crevices, thus producing erroneous measurements. However, the viscosity of the aerosol vehicle is low, and voids appear more often to be coated internally than sealed. Furthermore, the total volume of the wall coating material which is added can be made approximately the same in both the machined cavity and in the crater cases; therefore, error introduced as a result of displacement of the metered liquid by the wall coating material is taken into account in the case of the error evaluations using machined cavities.

REFERENCES

1. Bikerman, J. J. Surface Chemistry. Academic Press, Inc., New York, New York, 1947.

2. Goodman, E. H. "Description of Terminal Ballistics Ranges." AEDC-TDR-62-104 (AD 275362), May 1962.

3. Private communication, R. N. Cox, Royal Armament Research and Development Establishment, Fort Halstead, England, October 18-19, 1965.

4. Private communication, W. G. Howell, Denver Research Institute, Denver, Colorado, October 18-19, 1965.

5. Private communication, R. Waser, Naval Ordnance Laboratory, October 20, 1965.

6. Adam, N. K., and Morrell, R. S. and Samuels, H. "'Bloom' of Varnish Flows - I and II." Journal Soc. Chem. Ind., Vol. 53, p. 255T, 1934.

7. Ellefson, B. S. and Taylor, N. W. "Surface Properties of Fused Salts and Glasses: II. Contact Angle and Work of Adhesion on Gold and Platinum in Various Atmospheres." Journal American Ceramic Society, Vol. 21, No. 6, p. 205, June 1938.

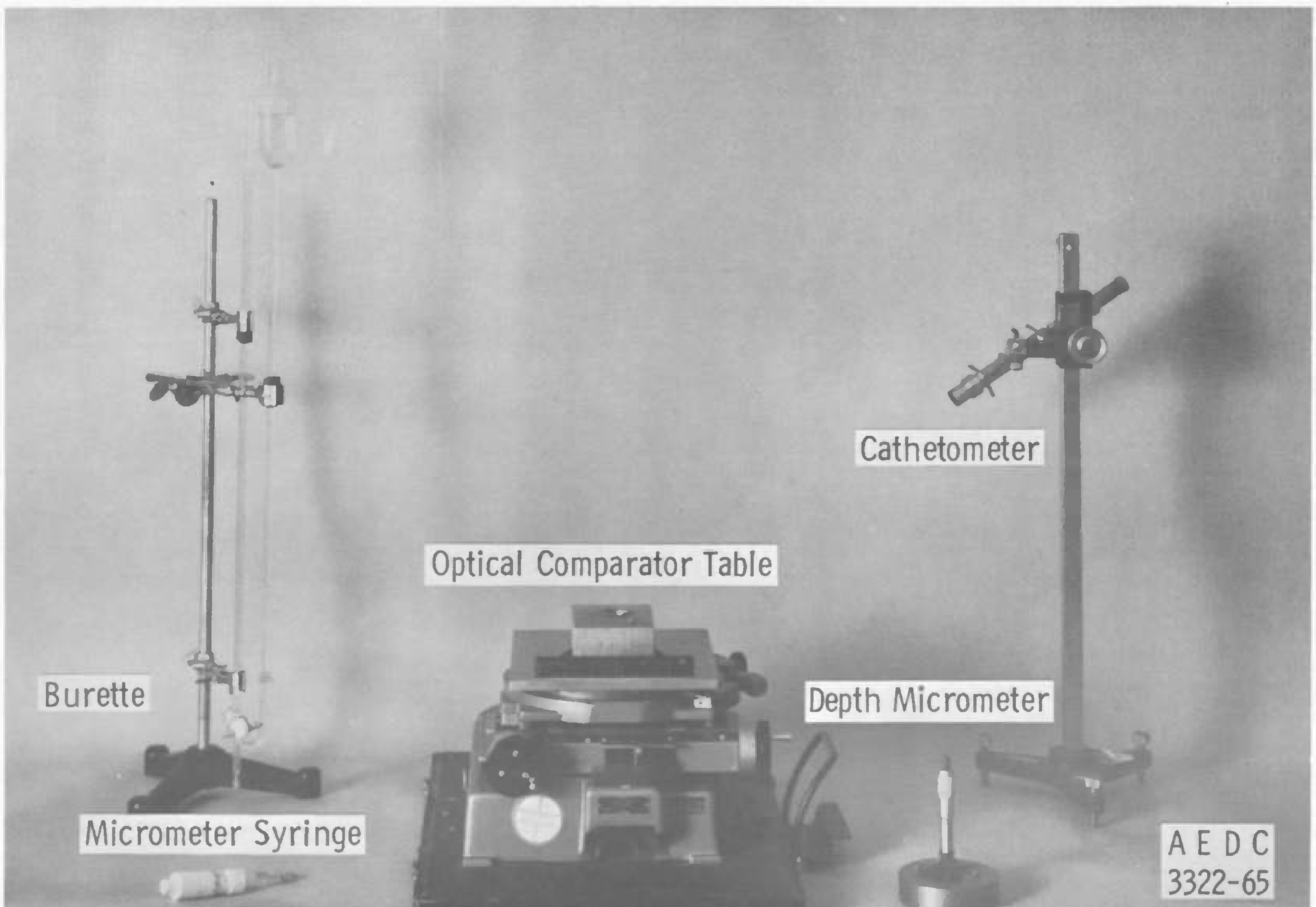

Fig. 1 Measuring Equipment

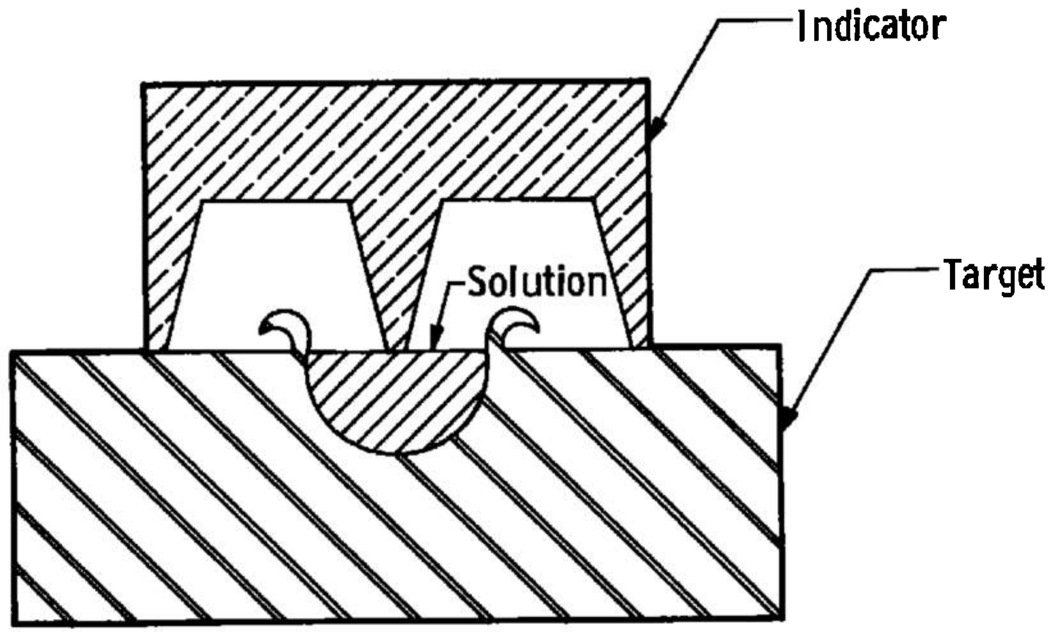

Fig. 2 Solution Level Determination Apparatus

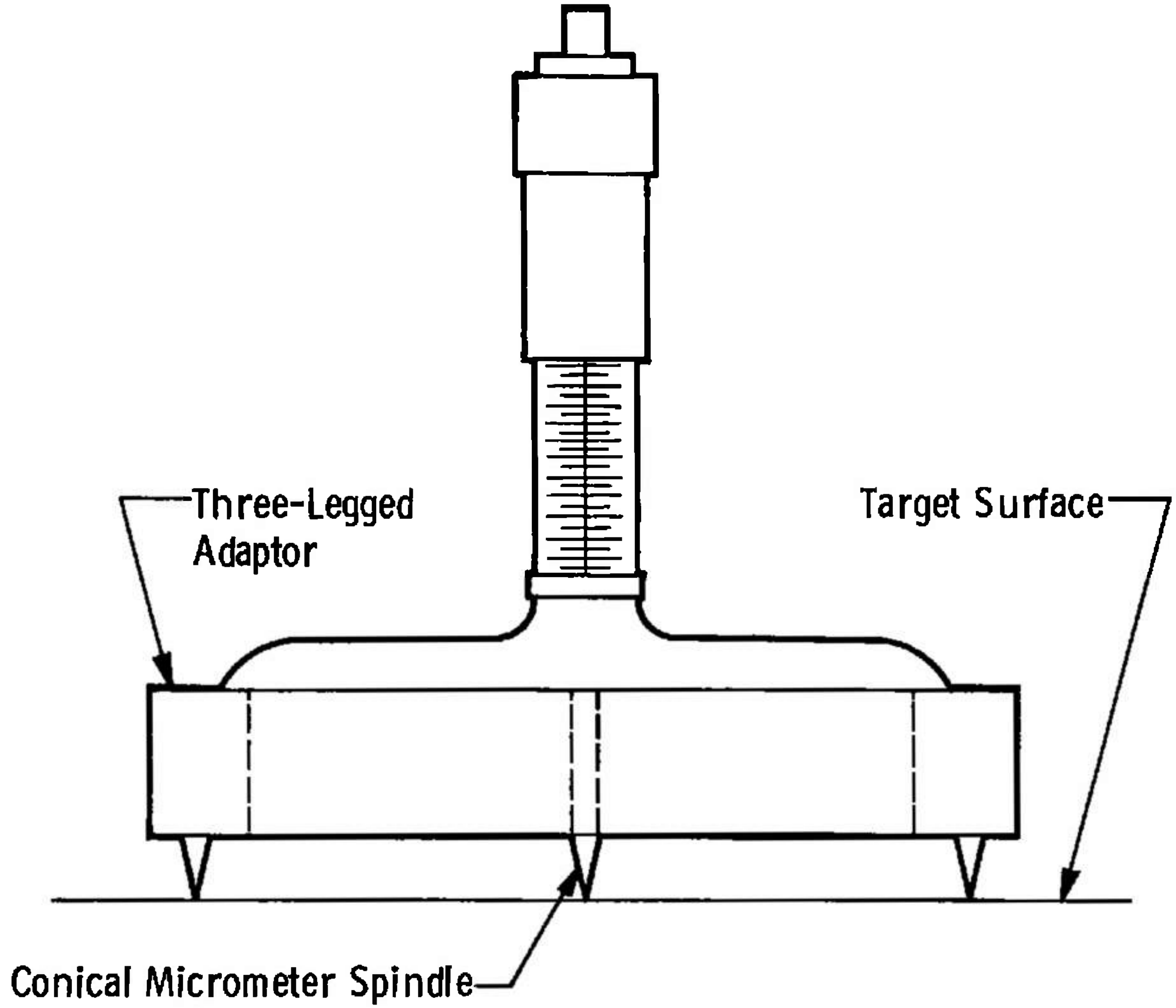

Fig. 3 Depth Micrometer with Adaptor

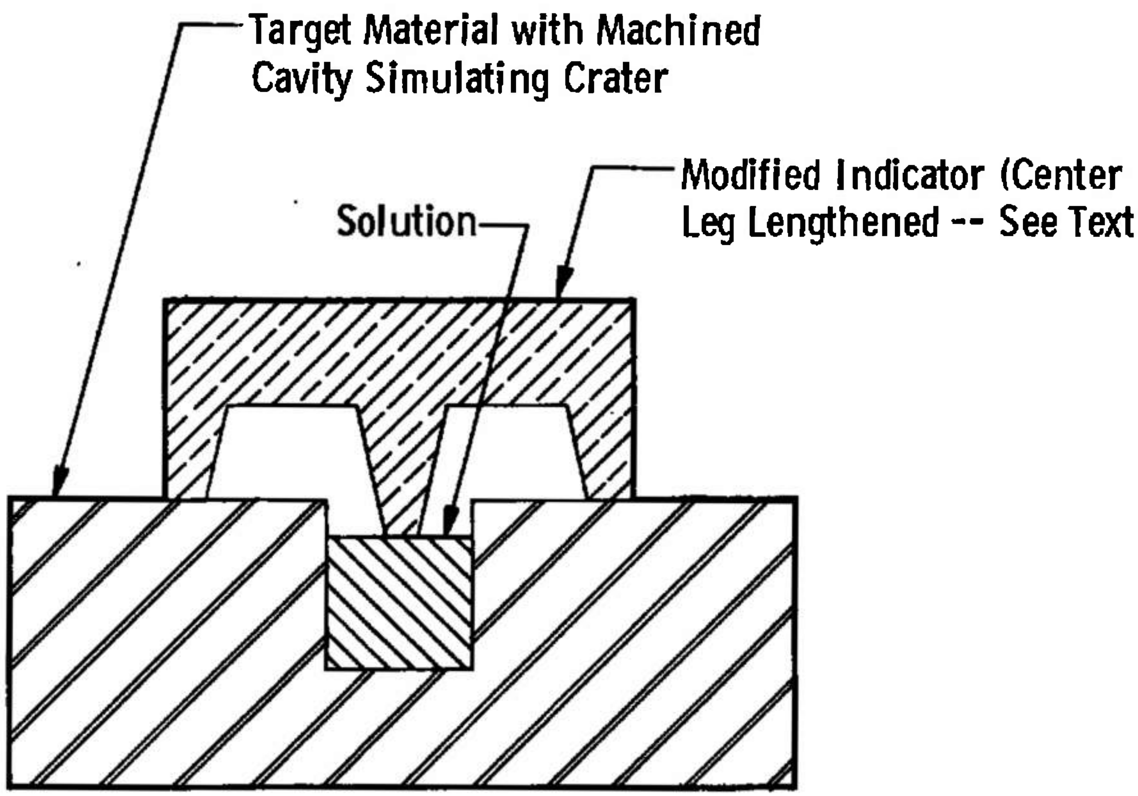

Fig. 4 Modified Solution Level Determination Apparatus

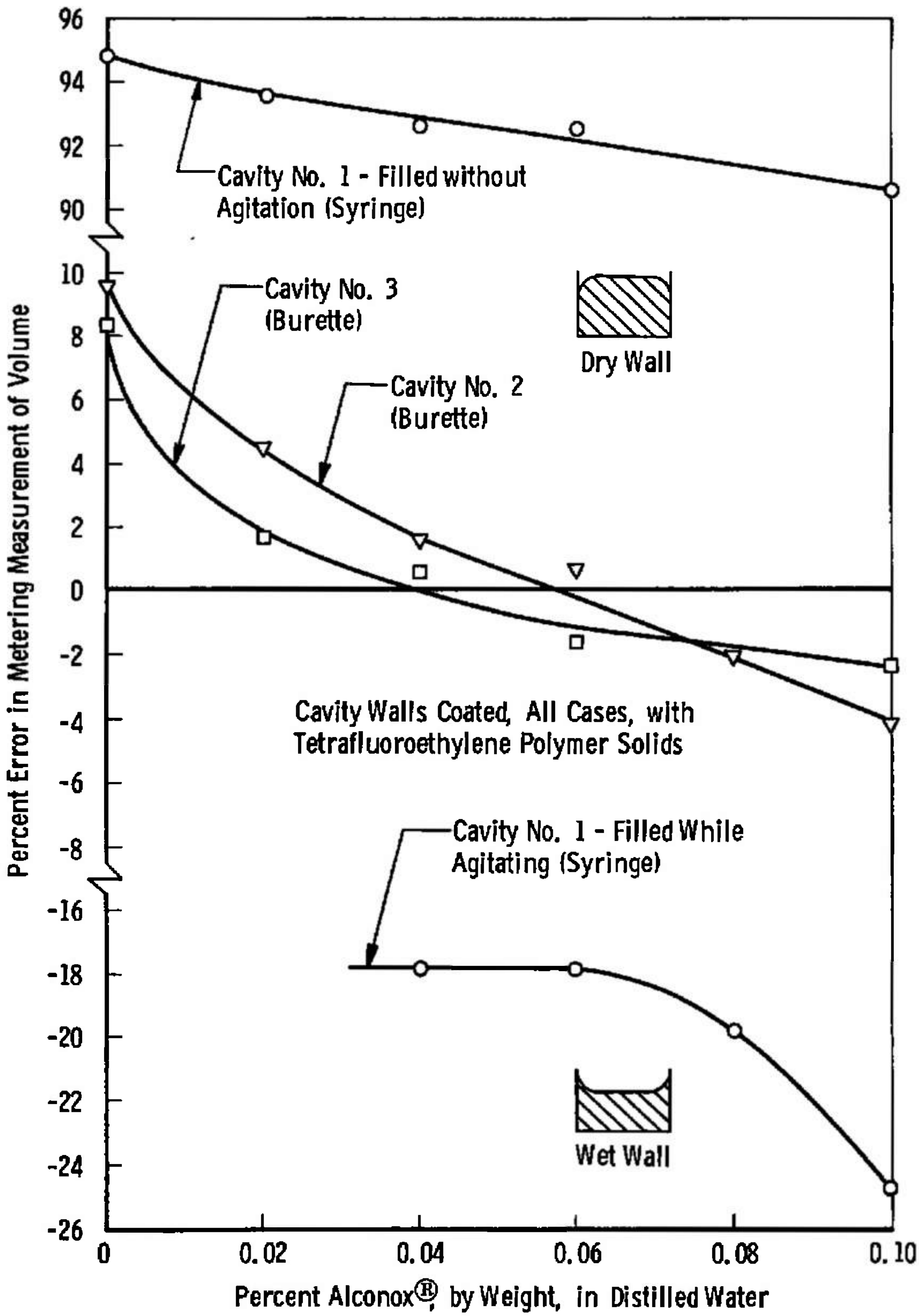

Fig. 5 Wetting Agent Optimization – Machined Cavities

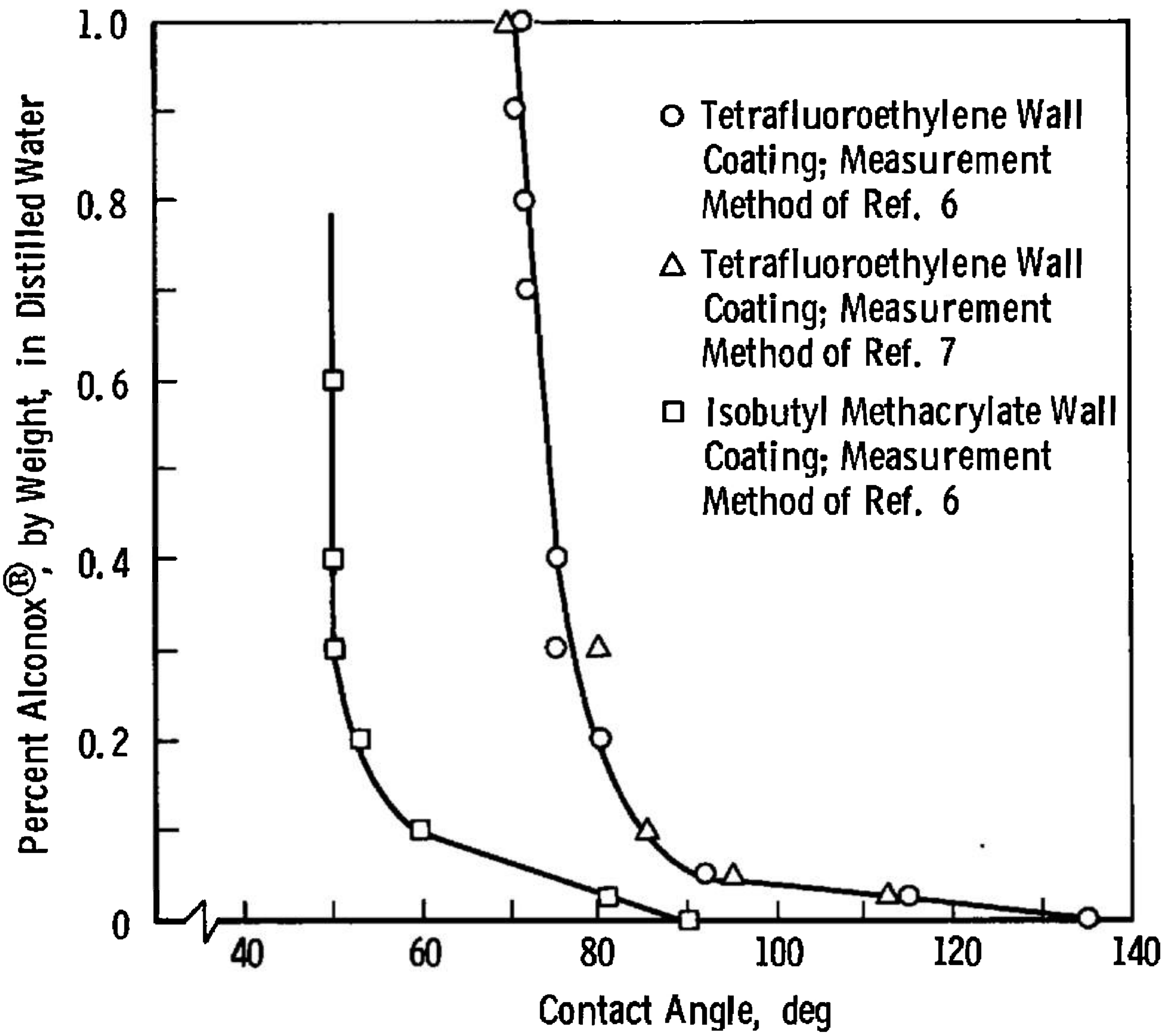

Fig. 6 Wetting Agent Concentrations to Produce Various Contact Angles

TABLE I
"AS MACHINED" DIMENSIONS OF STANDARD CAVITIES – 1100-F ALUMINUM

Cavity No.	Diameter, in.	Depth, in.	Computed Volume*	Modified Computed Volume**
1	0.3008	0.1498	0.0106 in.^{3} 0.1737 cc	0.00326 in.^{3} 0.0535 cc
2	0.5000	0.3000	0.0589 in.^{3} 0.957 cc	0.0384 in.^{3} 0.629 cc
3	0.8003	0.4998	0.2514 in.^{3} 4.11 cc	0.2000 in.^{3} 3.28 cc

*Volumes listed here are computed from the depths and diameters, as machined. Depths and diameters were measured by standard precision machine shop practices.

**Volumes listed here are computed from the depths, less the 0.1-in. extension of the liquid level indicator described in the text and shown in Fig. 4, and the diameters, as machined.

TABLE II

1 PERCENT ALCONOX STANDARD CAVITY VOLUME MEASUREMENTS

Cavity No.	"As-Machined" Modified Computed Volume,* cc	Average Measured Volume,** cc	Percent Error,***
1	0.0535	0.076 (syringe)	-44.0
2	0.629	0.715 (burette)	-13.7
3	3.28	3.515 (burette)	-7.16

*Volumes listed here are computed from the cavity depths, less the 0.1-in. extension of the liquid level indicator described in the text and shown in Fig. 4, and the cavity diameters, as machined.

**Measured volumes shown represent averages of four cavity fillings using syringe or burette, as indicated, and a solution of 1 percent Alconox, by weight, in distilled water dyed with 0.1-gm methylene blue per gallon. Before filling, cavities were cleaned with acetone and flushed with distilled water.

***Percent Error = 100 x (Modified Computed Volume - Average Measured Volume)/Modified Computed Volume)

TABLE III

0.05 PERCENT ALCONOX STANDARD CAVITY VOLUME MEASUREMENTS

Cavity No.	"As-Machined" Modified Computed Volume,* cc	Measured Volume,** cc	Percent Error***	Percent Scatter****
2	0.629	0.625		
		0.630		
		0.625		
		0.630		
	Average	0.628	+0.16	0.796
3	3.28	3.280		
		3.330		
		3.300		
		3.335		
	Average	3.311	-0.91	1.65

*Volumes listed here are computed from the cavity depths, less the 0.1-in. extension of the liquid level indicator described in the text and shown in Fig. 4, and the cavity diameters, as machined.

**Measurements shown were made using the burette and a solution of 0.05 percent Alconox, by weight, in distilled water dyed with 0.1-gm methylene blue per gallon. Before tetrafluoroethylene wall treatment, cavities were cleaned with acetone and flushed with distilled water.

***Percent Error = 100 x (Modified Computed Volume - Average Measured Volume)/(Modified Computed Value)

****Percent Scatter = 100 x (High Reading - Low Reading)/(Average Reading)

TABLE IV
CAVITY NO. 1 VOLUME MEASUREMENT - LEVEL FILL

"As-Machined" Computed Volume,* cc		Measured Volume,** cc	Percent Error***	Percent Scatter****
0.1737		0.174		
		0.174		
		0.174		
		0.174		
	Average	0.174	-0.17	0.00

*Volume listed here is computed from total cavity depth and diameter, as machined.

**Measurements shown were made using the micrometer syringe and a solution of 0.05 percent Alconox, by weight, in distilled water dyed with 0.1-gm methylene blue per gallon. Before filling, cavity was cleaned with acetone and flushed with distilled water. Cavity was filled level full, as determined using liquid level indicator shown in Fig. 2.

***Percent Error = 100 x (Computed Volume - Average Measured Volume)/(Computed Value)

****Percent Scatter = 100 x (High Reading - Low Reading)/(Average Reading)

TABLE V
SLOPING WALL STANDARD CAVITY VOLUME MEASUREMENTS

Wall Angle (See Sketch), deg	Wall Treatment	Percent Alconox by Weight	"As-Machined" Modified Computed Volume,* cc	Average Measured Volume (Syringe), cc	Percent Error**
80	TFE***	0.2	0.790	0.778	+1.52
75	TFE	0.6	0.608	0.618	-1.64
70	IM****	0.05	0.429	0.421	+1.75
65	IM	0.1	0.288	0.287	+0.347
55	IM	0.15	0.126	0.126	0.00
50	IM	0.3	0.079	0.080	-1.65

*Volumes listed here are computed from the cavity depths, less the 0.1-in. extension of the liquid level indicator described in the text and shown in Fig. 4, and the cavity diameters, as machined.

**Percent Error = 100 x (Modified Computed Volume - Average Measured Volume)/(Modified Computed Volume)

***Tetrafluoroethylene solids, applied as aerosol spray

****Isobutyl methacrylate, applied as aerosol spray

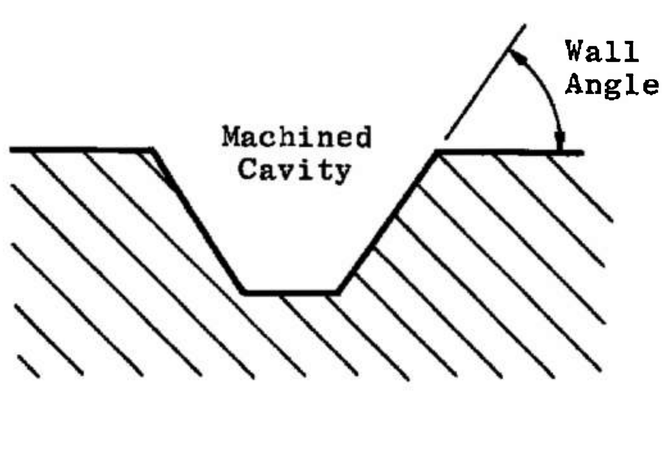

TABLE VI
SCATTER AND ACCURACY IN DIAMETER AND DEPTH MEASUREMENTS

	"As-Machined"		Measured		Measurements			
Cavity No.	Diameter, in.	Depth, in.	Diameter, in.	Depth, in.	Percent Scatter* Diameter	Percent Error** Diameter	Percent Scatter* Depth	Percent Error** Depth
1	0.3008	0.1498	0.2983	0.1499				
			0.2970	0.1502				
			0.2971	0.1504				
			0.2976	0.1504				
		Average	0.2977	0.1502	0.437	+1.04	0.333	-0.267
2	0.5000	0.3000	0.4968	0.3003				
			0.4978	0.3002				
			0.4940	0.3000				
			0.5031	0.3001				
		Average	0.4979	0.3002	1.828	+0.42	0.999	-0.067
3	0.8003	0.4998	0.8025	0.4992				
			0.8001	0.4995				
			0.8004	0.4997				
			0.8010	0.4992				
		Average	0.8010	0.4994	0.300	-0.0875	0.100	+0.080
				Average	0.855	+0.457	0.477	-0.051

$$\text{*Percent Scatter} = \frac{\text{High Reading} - \text{Low Reading}}{\text{Average Reading}} \times 100$$

$$\text{**Percent Error} = \frac{\text{"As-Machined" Value} - \text{Average Measured Value}}{\text{"As-Machined" Value}} \times 100$$

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED; 2b. GROUP N/A
3. REPORT TITLE HYPERVELOCITY IMPACT CRATER MEASUREMENT METHODS AND ACCURACIES		
4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* N/A		
5. AUTHOR(S) *(Last name, first name, initial)* P. L. Clemens and J. J. Payne, ARO, Inc.		
6. REPORT DATE May 1966	7a. TOTAL NO. OF PAGES 30	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. AF 40(600)-1200; b. PROJECT NO. 62405364; c. Project 8871; d. Task 887101	9a. ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-66-61; 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* N/A	
10. AVAILABILITY/LIMITATION NOTICES ~~Qualified users may obtain copies of this document from DDC. Document is subject to export controls and transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center.~~		
11. SUPPLEMENTARY NOTES N/A	12. SPONSORING MILITARY ACTIVITY Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tenn.	

13. ABSTRACT

Use has been made of cavities, machined in a typical hypervelocity impact target material, to evaluate methods used to measure volumes, depths, and diameters of impact craters. Depth and diameter measurement techniques in use have been found to produce errors, typically, of 0.1 and 0.5 percent, respectively. The liquid metering method of volume measurement has been found to produce large errors (7 to 44 percent) when applied in conjunction with the saturation wetting which is common. Wall coating and selective adjustment of wetting properties of the filling agent have been shown to provide effective means for minimizing meniscus errors; errors smaller than two percent result in cases where diameter is 0.5 in. or more and total volume exceeds 0.06 cc. The latter technique is inapplicable to accurate measurement of the volumes of small craters (diameters of 0.3 in. or less) wherein capilarity predominates; machining away of crater lips and metering level full produces more satisfactory results.

This document has been approved for public release its distribution is unlimited.

Per AF Letter dtd 15 Aug [illegible] signed William B. Cole

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1 impacting						
hypervelocity flow						
measurement						
2 craters --						
3 cavities --						
accuracy						
capilarity						
4 Holes --						

1-2.

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.